

# **A Procedural Approach to Authoring Solid Models**

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# Motivation

- Effects of time
- Material properties
- Internal structure



# Surface Modeling

- CSG
- Freeform deformation
- 3D scanning
- Difficult to modify



# Volumetric Modeling

- **Data acquisition**

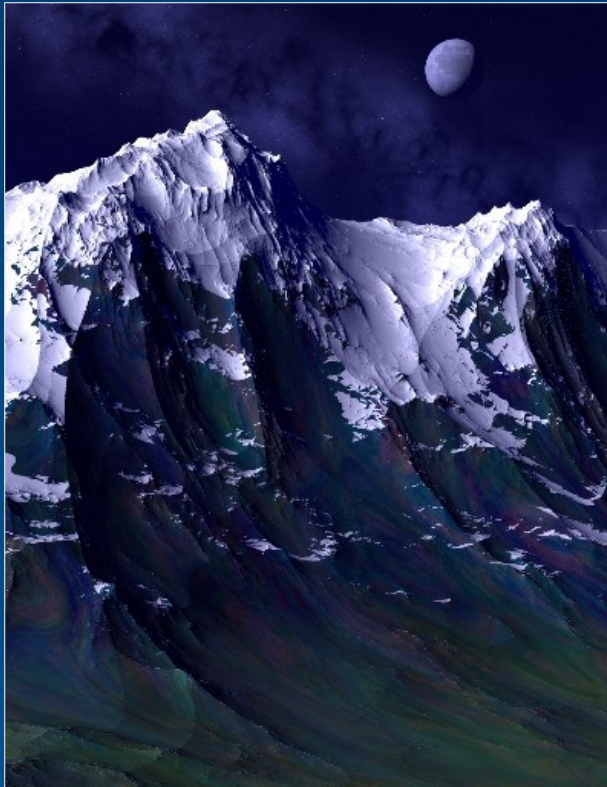
- Artist, cross-sections, MRI, tomography, etc.

- **Representations**

- Voxels, Octrees, ADFs [e.g., Frisken et al. 00]
- Surface-Volume Hybrid (Slabs) [Dorsey et al. 99]
- Tetrahedral Mesh [e.g., O'Brien and Hodgins 99]



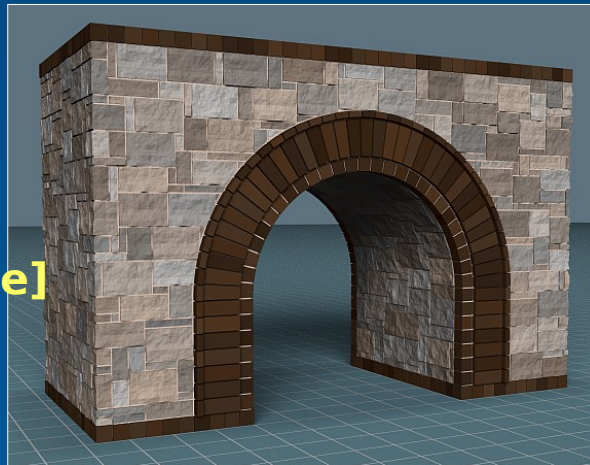
# Procedural Modeling



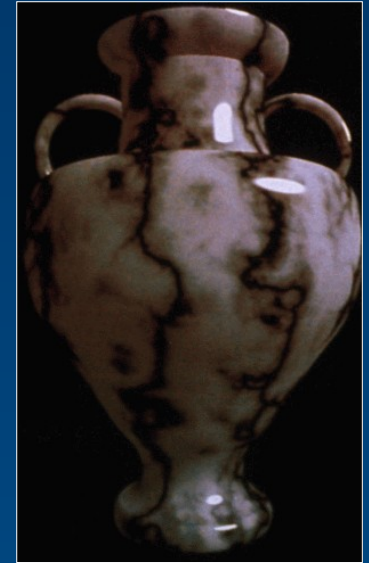
**Fractal Terrains [Musgrave]**



**L-systems [Prusinkiewicz]**



**Cellular Texturing [Legakis 01]**



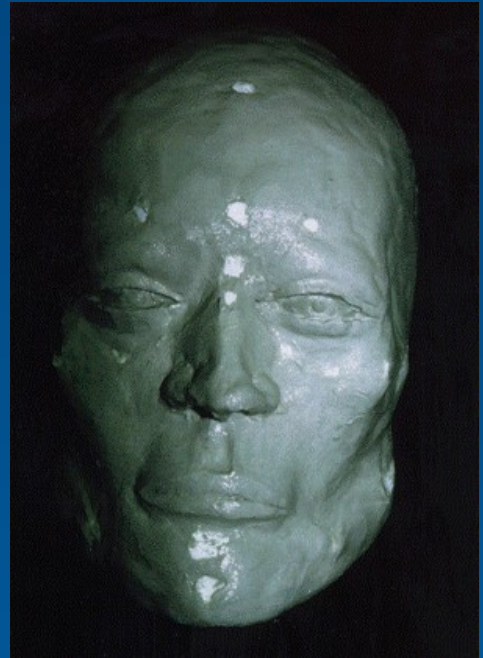
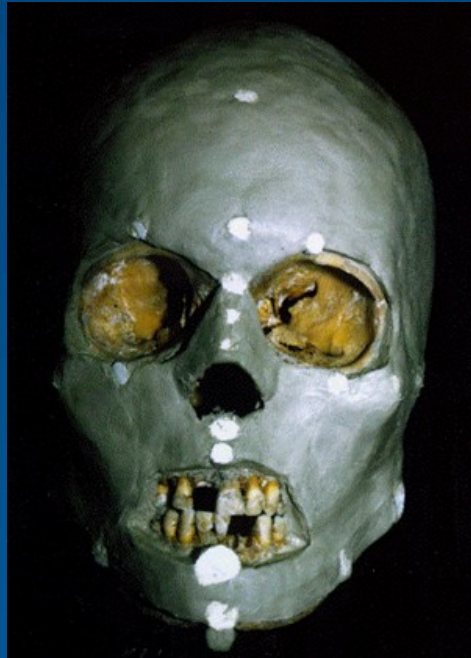
**Solid Texturing [Perlin]**



**Urban Modeling  
[Parish and Müller 01]**

# Layers are Everywhere

- Material built up over time
- Layer boundaries can be inferred



Martin Evison [1996]

# Key Contributions

- **Procedural approach to solid modeling**
  - Edit and refine incrementally
- **Simulation as a modeling operator**
  - Variety of simulation techniques in a single framework
- **Construction of tetrahedral models for FEM**



# Modeling Language Primitives

- Input surfaces
- Layers
- Materials
- Signed distance field
- Surface interactions
- Sculpting and simulation operators





# Input Surfaces

- **Polygon meshes**
  - Complex scanned meshes
  - Should be watertight
- **Implicit surfaces**



*Image to be  
re-rendered*

# Layers

```
CANDY = volume {  
  distance_field = surface_mesh {  
    file = "candy.obj" }  
  layers = {  
    interior_layer {  
      material = CHOCOLATE  
      thickness = fill } } }
```

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re-rendered*

*Image to be  
re-rendered*

# Layers

```
CANDY = volume {  
  distance_field = surface_mesh {  
    file = "candy.obj" }  
  layers = {  
    interior_layer {  
      material = CHOCOLATE  
      thickness = fill }  
    exterior_layer {  
      material = WHITE_CHOCOLATE  
      thickness = 1.0 }  
    exterior_layer {  
      material =  
STRIPED_CHOCOLATE  
      thickness = 1.0 } } }
```



*Image to be  
re-rendered*

# Layers

```
CANDY = volume {  
  distance_field = surface_mesh {  
    file = "candy.obj" }  
  layers = {  
    interior_layer {  
      material = CHOCOLATE  
      thickness = fill }  
    exterior_layer {  
      material = WHITE_CHOCOLATE  
      thickness = 3.0 }  
    exterior_layer {  
      material =  
STRIPED_CHOCOLATE  
      thickness = 1.0 } } }
```

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re-rendered*

*Image to be  
re-rendered*



# Layers

```
CANDY = volume {  
  distance_field = surface_mesh {  
    file = "candy.obj" }  
  layers = {  
    interior_layer {  
      material = CHOCOLATE  
      thickness = fill }  
    exterior_layer {  
      material = WHITE_CHOCOLATE  
      thickness = 3.0 }  
    exterior_layer {  
      material = WAVY_CHOCOLATE  
      thickness = 1.0 } } }
```

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re-rendered*

# Materials

- **Rendering and simulation parameters**
- **Built-in and user-defined materials**
- **Default values for unspecified parameters**

```
CHOCOLATE = material {  
    diffuse_color = { 0.31 0.17 0.15 }  
    shininess = 10  
    density = 1100 /* kg/m^3 */  
    elasticity = 1.0e5 /* N/m^2 */ }
```

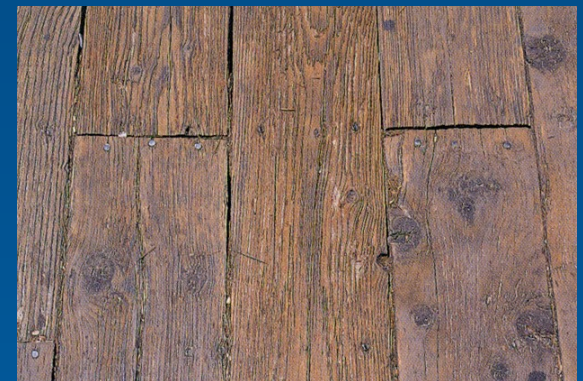
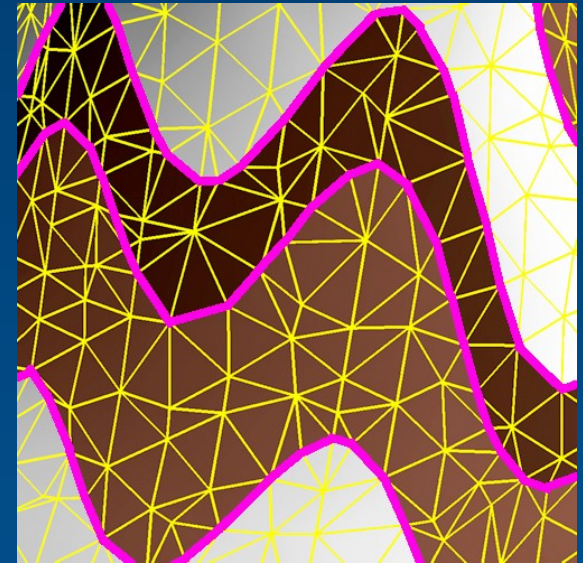
# Procedural Material Variations

- **Distinct materials within layer**

- Striped chocolate
- Brick and mortar walls
- Wood framing and insulation

- **Solid Texturing**

- concrete
- wood grain



# Signed Distance Field

- Continuous scalar function
- Level Sets [Sethian]
- Advantages:
  - Prevents self-intersection
  - Allows changes in topology
  - No min or max thickness





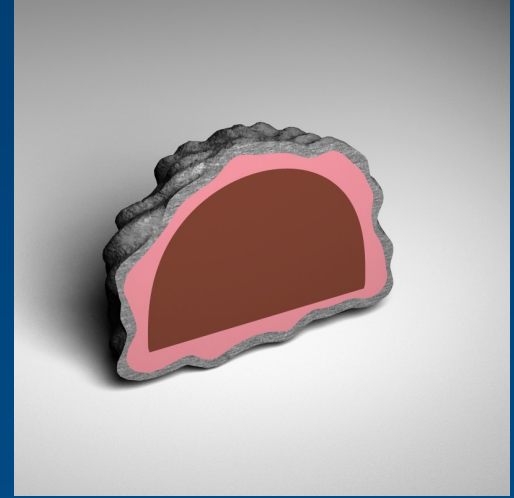
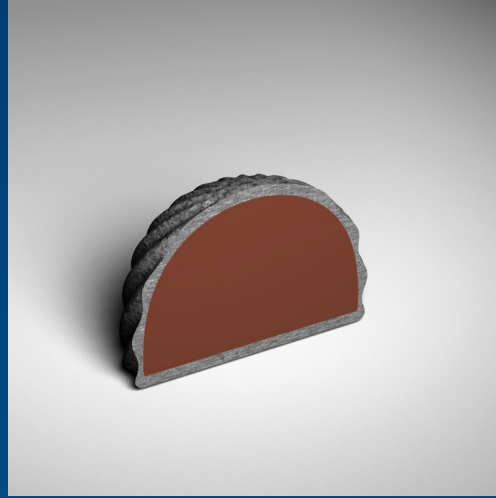
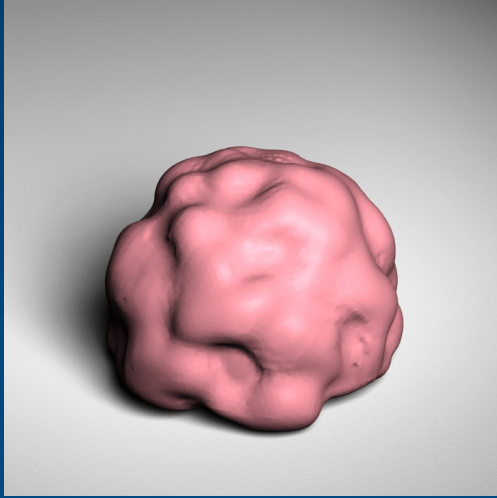
# Non-uniform Isosurface Velocity

- **Non-Euclidean distance metrics:**
  - User-painted
  - Turbulence
  - User-defined procedures
  - Accessibility, visibility, etc.

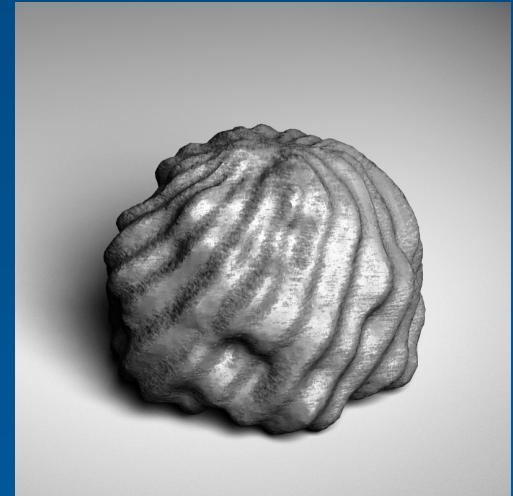
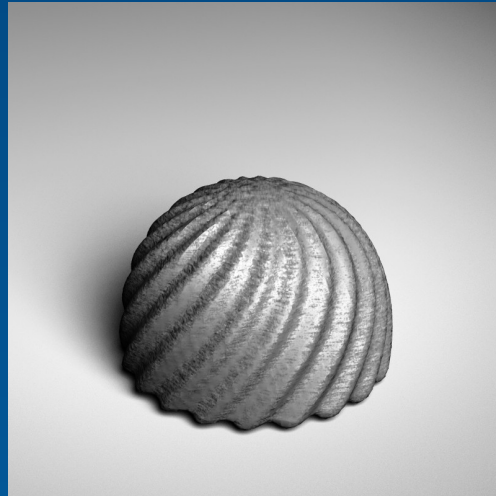


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# Non-uniform Isosurface Velocity



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# Mesh Interaction

- **Precedence:  
unused space  
claimed  
by subsequent  
volumes**

```
ALMOND_CANDY = precedence {  
  volume_1 = ALMOND  
  volume_2 = CANDY }
```

*Image to be  
re-rendered*



# Intermediate Shapes

- Add layers to intermediate volume

```
ALMOND_CANDY_2 = volume {  
  distance_field = from_volume {  
    volume = precedence {  
      volume_1 = ALMOND  
      volume_2 = CANDY_INTERIOR }}  
  layers = EXTERIOR_LAYERS }
```



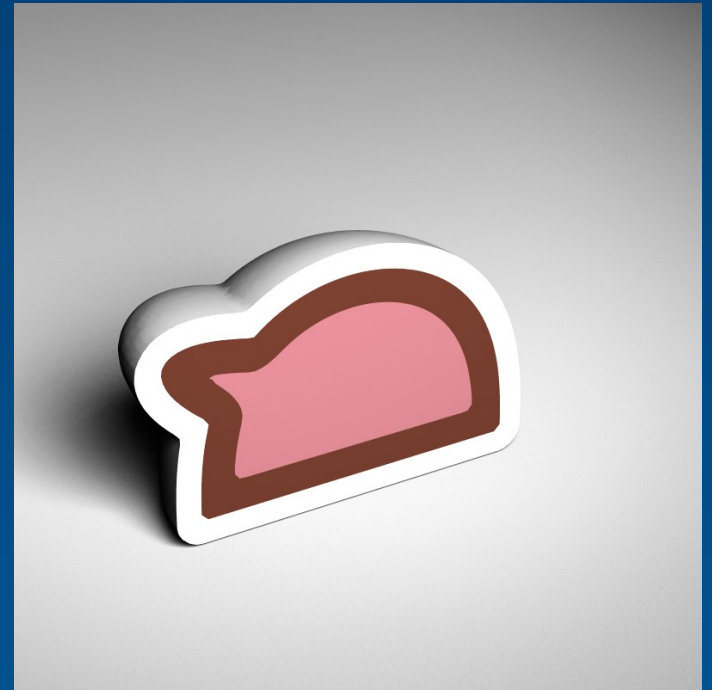
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# Distance Field Operators

- **Combine distance fields, CSG style**

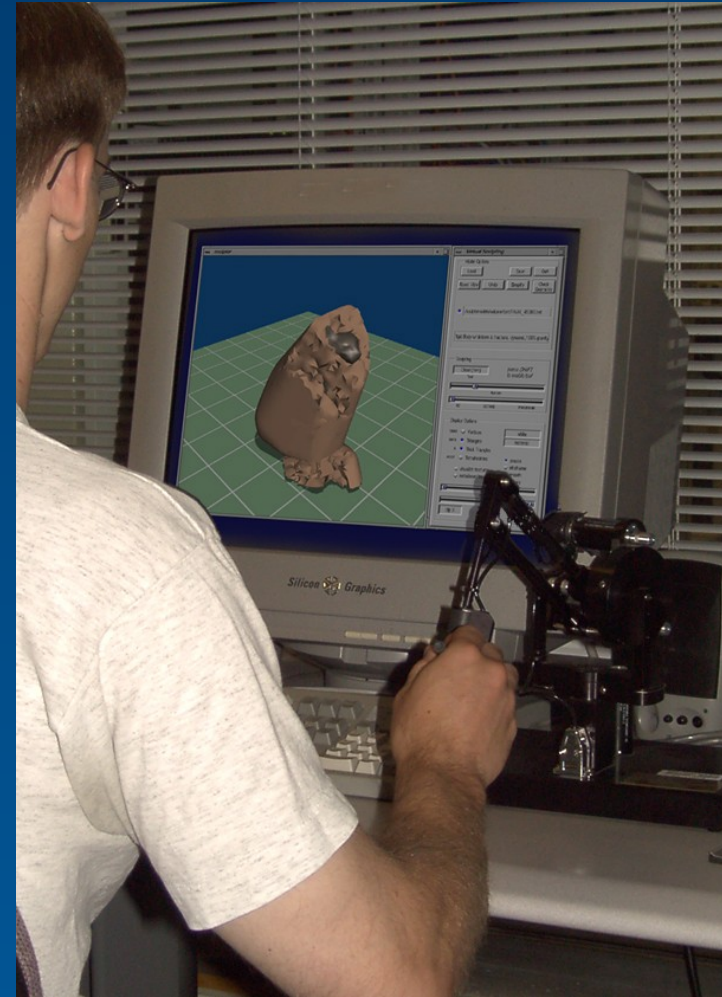
```
UNION_CANDY = volume {  
  distance_field = union {  
    distance_field_1 = ALMOND  
    distance_field_2 = CANDY }  
  layers = LAYERS }
```



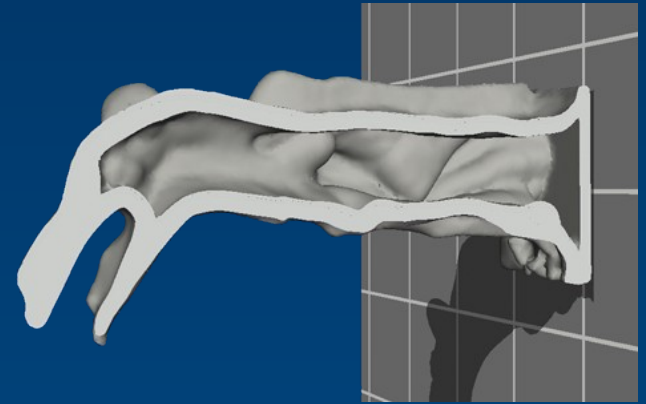
*Image to be  
re-rendered*

# Sculpting Operators

- **Standard tool interface**
  - CSG, Finite Element Method, etc.
- **Customizable behavior**
  - Particle system
- **Language as intermediate representation**
  - Interactive sculpting actions logged and replayed on high resolution mesh



```
GARGOYLE = volume {  
  distance_field = surface {  
    file = gargoyle.obj  
  }  
  layers = interior_layer {  
    material = STONE  
    thickness = 0.5 } }  
}
```

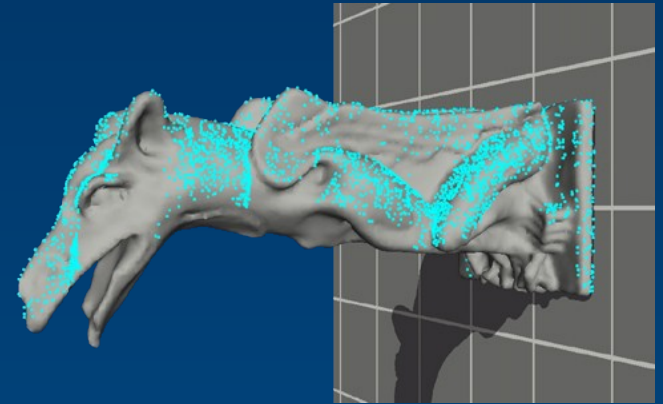


```
DIRT {  
    color = { 0.5 0.5 0.5 } }
```

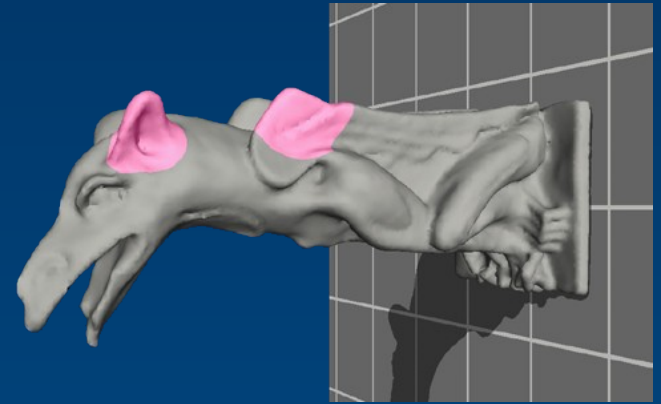




```
WASH {  
  num_particles = 200000  
  particle_motion = CLINGING }
```

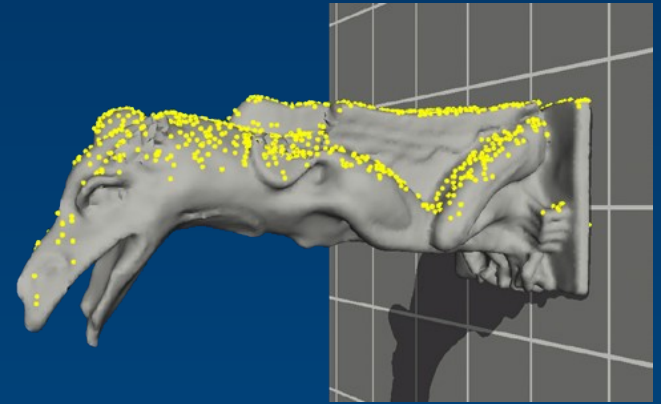


```
HAMMER {  
  position = { -0.78 1.22 0.77 }  
  orientation = { -0.23 -0.47 0.85 } }  
HAMMER {  
  position = { -2.53 1.03 1.06 }  
  orientation = { 0.56 -0.19 -0.80 } }
```





```
ERODE {  
  size = 0.1  
  num_particles = 2000 }
```

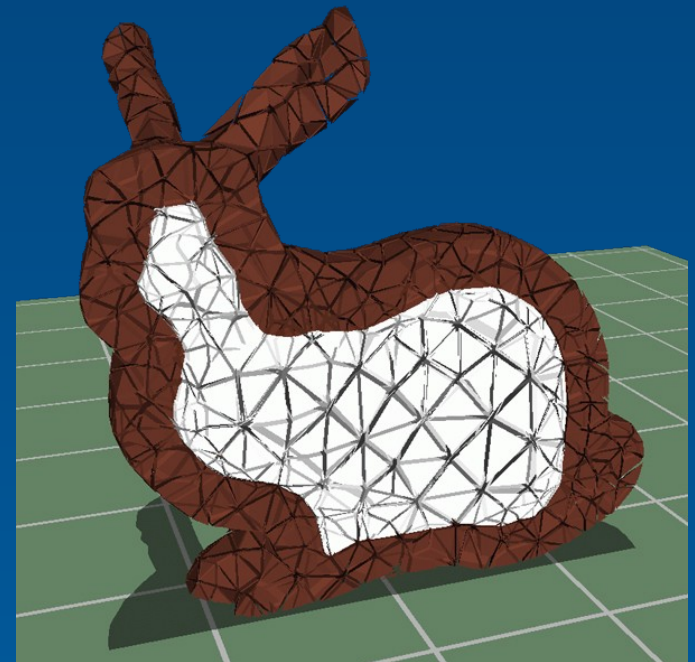
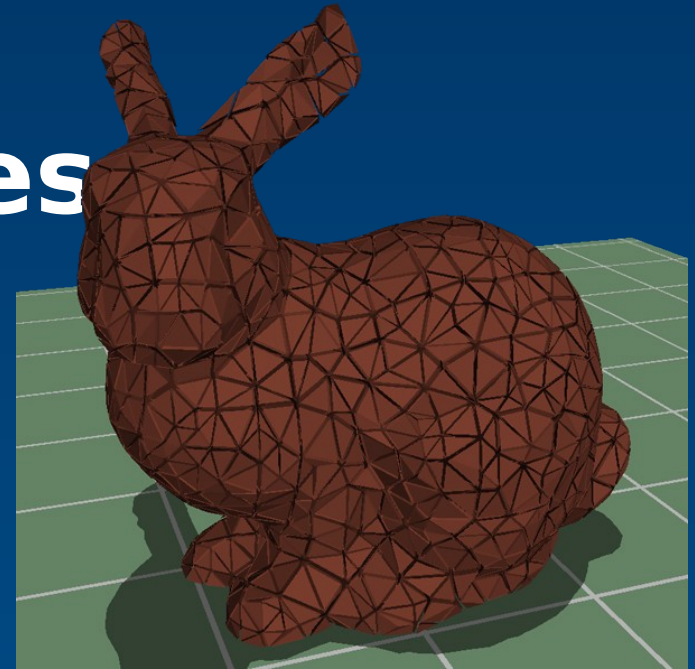


```
BIOLOGICAL_GROWTH {  
  num_particles = 40000 }
```



# Tetrahedral Meshes

- Naturally adaptive
- Maintain corresponding triangle mesh
- Voxel/Octree construction method [Nielson and Sung 97]
- Simplification and mesh improvement





# Tree Stump

- Tree stump is cylinder plus noise
- Roots extruded from image



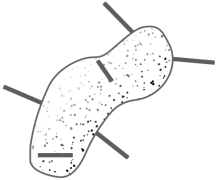




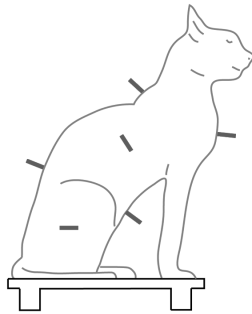


# Lost Wax Casting

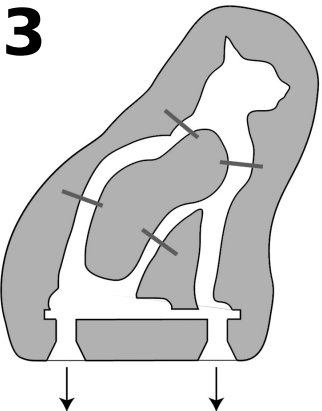
1



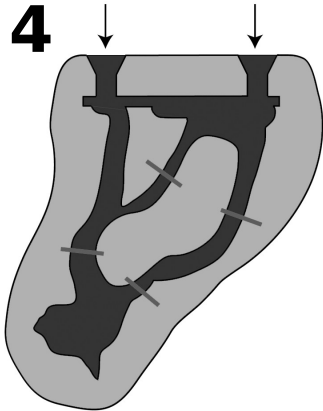
2



3



4

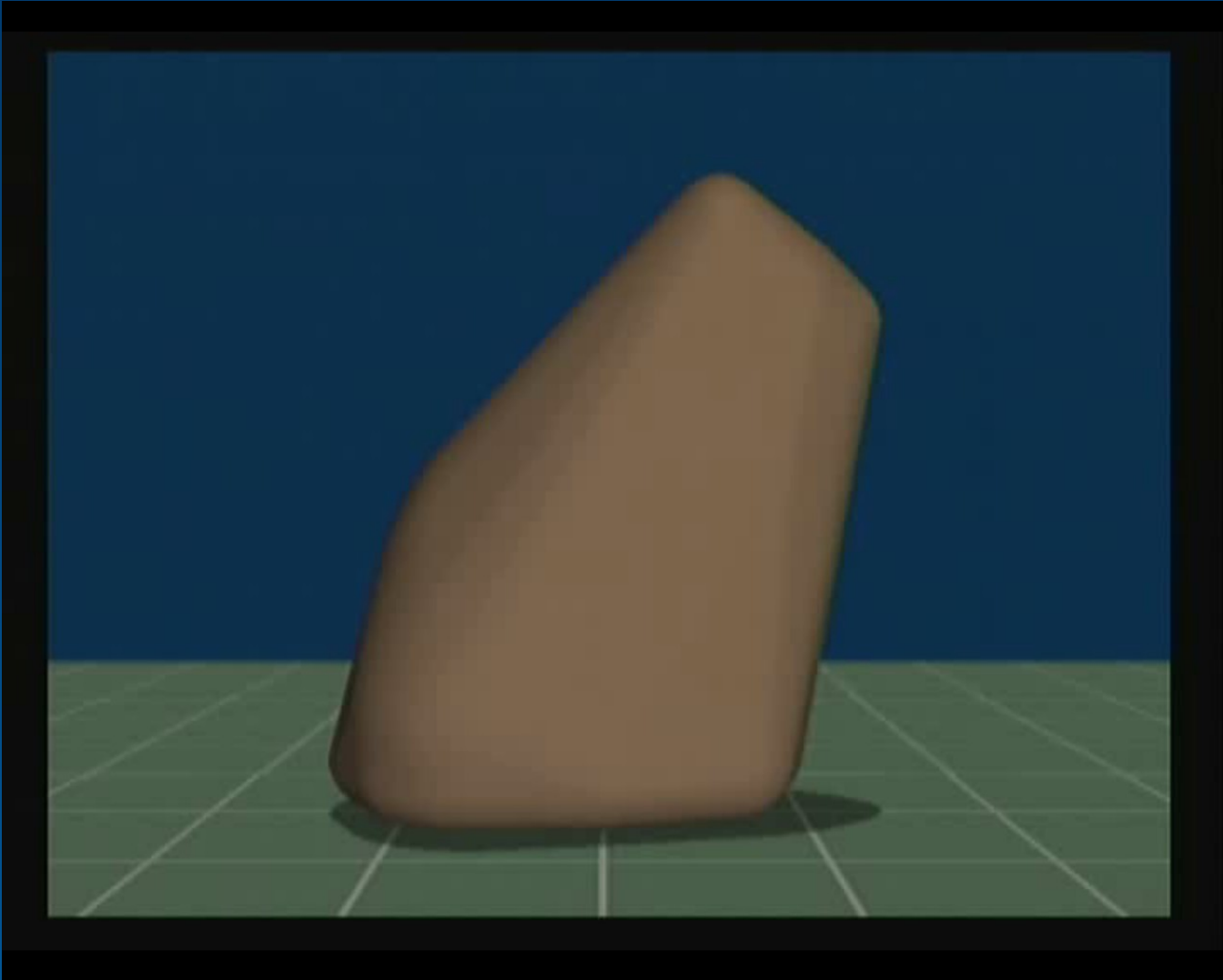


5

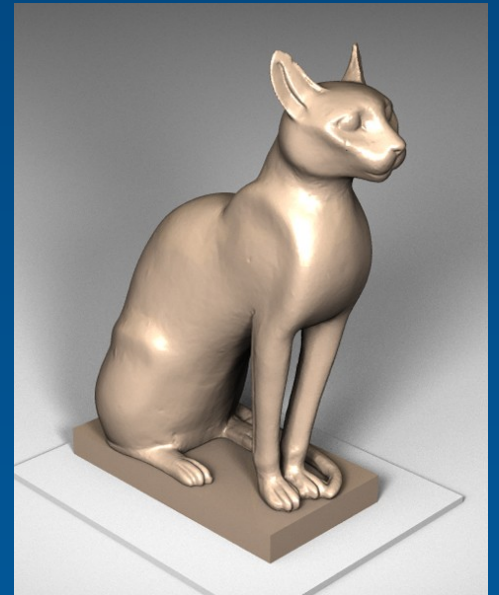
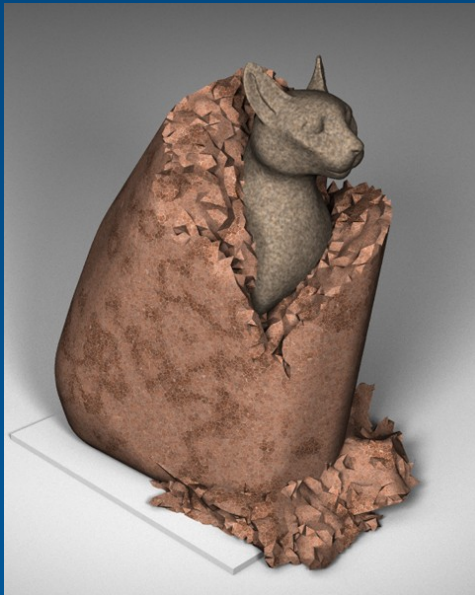
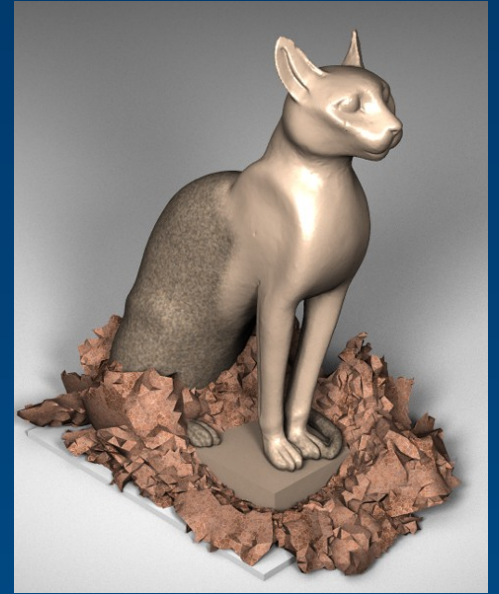
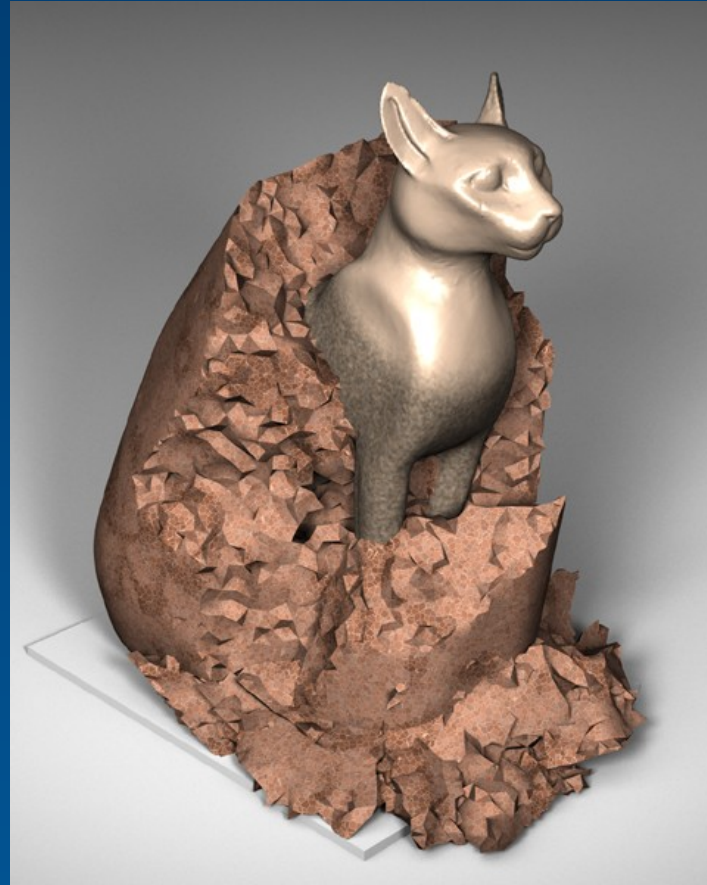
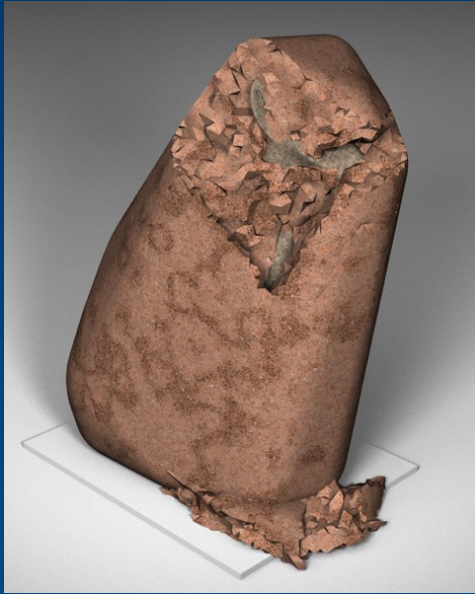


Henry Hodges [1970]

Tuck Langland [1999]







# Conclusions

- **Procedurally create and modify volumetric models**
- **Models for interactive and offline simulations**
- **Edit & replay sculpting actions**
- **High level interface to simulation**

# Future Work

- **New modeling and simulation tools**
- **Materials with intricate internal structures**
- **Scalability**





# Acknowledgements

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